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MODERN ACHIEVEMENTS OF COSMONAUTICS

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ANNOTATION

Glorious pages in the heroic annals of the conquest of space have been written in the past year, by the flights of the Soviet unmanned spacecraft Luna-21, which delivered Lunakhod-2 to the surface of our natural satellite, and the Prognoz, Kosmos and other series of earth satellites. Working consultations are continuing, on conduct of the important international experiment of docking the Soyuz and Apollo spacecraft in 1975.

The collection, compiled mainly from materials published in the central press, tells of these achievements. The commentaries of well-known Soviet scientists and engineers acquaint the readers with an extensive group of problems.

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16. Abstract

These articles discuss some Soviet achievements in space exploration and possible future areas and means of space research. The role of automation and computer technology is discussed. A brief history of lunar landings is given and, primarily, the instrumentation and preliminary results of the operation of Lunakhod-2 on the moon are presented. Conditions for compatibility of different spacecraft and the solutions arrived at for the Apollo-Soyuz flight are discussed. The results of visual observation of the twilight aureole from space are presented. Possible models of the origin and consequences of solar outbursts and the results of magnetic, shortwave electromagnetic radiation and charged particle measurements by Prognoz satellite instruments are presented. Development of the quantum amplifier in the Soviet Union and Soviet achievements and prospects in planetary radar ranging, super-long baseline radio interferometry and remote space communications are discussed.

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MODERN ACHIEVEMENTS OF COSMONAUTICS

Automation in Space

B. Petrov

Efficient interaction between man and machine, man and technical systems, which he develops and which he controls, is becoming one of the most urgent problems of science. A clear example of effective use of automatic systems is the study and conquest of space, where the capabilities of modern automation, computer technology and radioelectronics have been displayed in all their fullness. In this field as nowhere else, the problem of efficient combination of the use of automatic means and study with human participation is acute. The problem of interaction of people and automatic devices is especially urgent. /3*

Three basic areas can be distinguished here: the building of automatic means, which completely solve problems without human participation; continuous or periodic control of unmanned space vehicles by a man, located on earth; flights of man in space and control of space vehicles (spacecraft, orbital stations), instruments and experimental units aboard these vehicles.

In space, as in no other sphere, if you please, automatic machines are paving the road for people. They conduct explorations, bring in the first data on space and only then does man's turn come. Artificial earth satellites are used for solving many practical problems. They carry communications, meteorological and navigation satellite services. It is difficult to overestimate the importance of satellites for study of earth resources. For many years

*Numbers in the margin indicate pagination in the foreign text.

yet, unmanned spacecraft will remain the only means of direct study of remote space and the planets.

Mobile research laboratories, of the Lunakhod type, obediently obey the commands of the crew, nearly 400 thousand km distant. For this, scientists have to create a complex system of automatic control, on the basis of information transmitted from aboard the Lunakhod to earth. /4

An example of the complex study of space, with direct participation of people, was the unique experiment, performed by means of the first scientific orbital station, Salyut. In full measure, it revealed the capabilities of man aboard an orbital station, equipped with diverse systems and equipment with automated remote and manual control. The launch of the Salut-type station was the beginning of a long road, along which astronautics undoubtedly will pass in the conquest of space.

What are the prospects of development of astronautics and use of its achievements in the name of man? We dwell on only a few problems, connected with development of automatic control means.

The creation of a complex automated system of processing scientific information obtained from satellites, which immediately presents the results of an experiment in a form, which is convenient for the investigator, is on the agenda. In this case, preliminary processing of data aboard a spacecraft is possible. This permits more efficient use of the radio channels for transmission of information to earth. The use of computers provides the capability of not only passively recording the data received, but of actively controlling the experiment, depending on the results of it.

The problem of building planet rovers presents specialists in the field of control with the most complicated tasks. To say nothing of the difficulties of development of automatic systems of high reliability for the severe conditions of space, the process itself of control of such a vehicle requires a completely new approach. The tremendous distance to even the nearest planets leads to delay of the signals. This practically excludes direct remote control of a planet rover and requires new solutions, for example, automated systems, capable of working for a specific time in the autonomous mode. If the tasks of such vehicles also include performance of /5 some operations on the surface of the planet, soil sampling and analysis or moving over a complicated topography, the problem arises of construction of robots, made with elements of an artificial intellect.

Such vehicles, multi-level hierarchic systems, will periodically receive commands to conduct experiments and to put them into practice independently. Scientific information goes through preliminary processing aboard such vehicles, before transmission to earth.

Specialists in the field of navigation are faced with much work, in order to provide for movement of planet rovers, such as Lunakhods, along a part of the surface of a planet or the moon invisible from earth. Special navigation satellites of a planet or of the moon, as well as use of part of the apparatus of research satellites for this purpose, turn out to be very useful for solution of this problem.

There are interesting prospects for use of various space complexes, for example, combined systems, consisting of Luna-16 and Luna-20 type unmanned spacecraft and Lunakhods. They could collect samples of the soil from various parts of the moon, deliver them to the launch site of the moon-earth rocket and place them, together with materials from other experiments, in the return container of this rocket. Similar, but many times more difficult problems are introduced in study of the planets of the solar system.

One of the major areas of development of astronautics is long-term manned orbital stations. The presence of a crew on board not only does not decrease the role of automatic resources but, on the contrary, increases it. Their tasks include maintenance of normal life support conditions of the astronauts, orientation, stabilization and maneuvering of the station with high reliability, in both the manual and automatic control modes. Efficient performance of experimental work and scientific observations is impossible, without automatic systems for control of scientific equipment and automation of at least the primary processing of the information.

In perspective, the creation of special, automated, remotely /6 controlled, unmanned and manned maintenance stations, intended for both repair and replacement of individual units in research satellites and satellites for national economy purposes, and for outside maintenance of long-term orbital stations, is urgent.

Such maintenance stations will have to be equipped with manipulators, for performance of various operations in space, with automatic devices and with computer technology resources. These systems will be controlled, for example, both from aboard the orbital station itself and directly by a man, located in the cabin. Maintenance stations are represented as cybernetic devices, in the broadest and most complete sense of this word. In the longer perspective, they will be able to perform various assembly operations, in assembling large stations in orbit, and to weld their hulls from rolls of sheet material, delivered by separate transport rockets. The stations could be used for assembly of large radio-telescope antennas in orbit and performance of other operations in space.

It would not be an exaggeration to say that an avalanche-like process will begin in the near future, in the course of which, new and complex problems of study and conquest of space will pose more and more difficult tasks for automatic systems. Progress in their development and improvements in radio-electronics, computer and laser technology resources are opening new horizons in the conquest of space and use of space technology for peaceful purposes.

Lunakhod-2 in Lemonnier Crater

A. Koval' N75 22257

In 1973, 16 years had elapsed from the day when the first /7 space vehicle rose into universal space. During this time, the moon, the nearest heavenly body to us, has undergone particularly thorough studies. This was not accidental. Our natural satellite has long attracted the attention of mankind.

Study of the moon is giving us new capabilities, not only for perception of space, but for study of our own planet, knowledge of which, together with a general scientific importance, also has great practical importance. In fact, we would like to know the physics and structure of the earth, so as to be able to exploit the mineral resources at great depths, so as to understand and know how to predict and, in the future, control the weather, in order to avoid the undesirable aftereffects of natural disasters (earthquakes, volcanic eruptions, etc.). The moon is so close (of course, on a cosmic scale) to the earth that it forms a double planet with it, as it were. The circumstance that conditions on the moon are very different from ours (there is no atmosphere, hydrosphere, magnetic field, etc.) is precisely the most favorable for its use as an example (like a model) for studying the historic past of the earth, where the waters of the world ocean, atmosphere and activities of living organisms have completely changed its appearance. All the geological, geophysical and geochemical methods of study of the earth let us obtain a certain idea about a very short period of the cosmic history of our planet, only during the last 500 million years. At the same time, according to modern ideas, the age of the earth and the moon is at least 4.5 billion years. Therefore, many basic patterns of formation and structure of the earth as a planet still /8 have not been unambiguously interpreted.

Lunakhod-2 was sent to the moon, by means of the unmanned Luna-21 spacecraft, launched on 8 January 1973. This was the first spacecraft sent from earth in 1973. Therefore, it received the international designation 1973 01A. In the short but history-saturated study of the moon, this was the 17th vehicle accomplishing a soft landing on its surface (see table). The landing was accomplished inside the 55 km crater, dedicated in the name of the 18th century French astronomer, Lemonnier. The landing point coordinates: 30°27'E longitude and 25°51'N latitude, not far from the southern edge of the crater. This area was selected for the reason that it is in a complex zone of the joining of mare and highlands. This was the first study of such a mare-highland transition zone. Moreover, a very interesting selenological structure, a tectonic fracture, which was given the name of Straight Rille, was located not far from the landing site. The Taurus Mountains, which are seen well in a photograph taken from Lunakhod shortly after landing, were located to the east of Lemonnier Crater.

Spacecraft Accomplishing a Soft Landing on the Surface of the Moon

No.	Spacecraft Name, Its International Designation, Country	Launch Date and Moon Landing Date (Greenwich)		Landing Area	S[illegible]nographic Coordinates
1	2	3	4	5	6
1	Luna-9 1966 06 A USSR	31 Jan 1966	3 Feb 1966	Ocean of Storms, between Galileo and Cavalerius Craters	7.1°N lat 64.4°W long
2	Surveyor-1 1966 45 A USA	30 May 1966	2 June 1966	Ocean of Storms, north of Flamsteed Crater	2.5°S lat 43.2°W long
3	Luna-13 1966 116 A USSR	21 Dec 1966	24 Dec 1966	Ocean of Storms, southeast of Seleucus Crater	18.9°N lat 62.0°W long
4	Surveyor-3 1967 35 A USA	17 April 1967	20 April 1967	Ocean of Storms, southeast of Landsberg Crater	3.0°S lat 23.3°W long

1	2	3	4	5	6
5	Surveyor-5 1967 84 A USA	8 Sept 1967	11 Sept 1967	Sea of Tranquility east of Sabine Crater	1.4°N lat 23.2°E long
6	Surveyor-6 1967 112 A USA	7 Nov 1967	10 Nov 1967	Central Bay	0.5°N lat 1.4°W long
7	Surveyor-7 1968 01 A USA	7 Jan 1968	10 Jan 1968	North of Tycho Crater	40.9°S lat 11.5°W long
8	Apollo-11 1969 59 A USA	16 July 1969	20 July 1969	Sea of Tranquility, east of Sabine Crater	0.7°N lat 23.5°E long
9	Apollo-12 1969 99 A USA	11 Nov 1969	19 Nov 1969	Ocean of Storms, southeast of Landsberg Crater	3.2°S lat 23.4°W long
10	Luna-16 1970 72 A USSR	12 Sept 1970	20 Sept 1970	Sea of Fertility, west of Webb Crater	0.7°S lat 56.3°E long
11	Luna-17 1970 95 A USSR	10 Nov 1970	17 Nov 1970	Sea of Rains, south of Heraclides Promontory	38.3°N lat 35.0°W long
12	Apollo-14 1971 08 A USA	31 Jan 1971	5 Feb 1971	North of Fra Mauro Crater	3.7°S lat 17.5°W long
13	Apollo-15 1971 63 A USA	26 July 1971	30 July 1971	East of Hadley Rille	26.1°N lat 3.6°E long
14	Luna-20 1972 07 A USSR	14 Feb 1972	21 Feb 1972	Northeast of Apollonius Crater	3.5°N lat 56.5°E long
15	Apollo-16 1972 31 A USA	16 April 1972	21 April 1972	North of Descartes Crater	9.0°S lat 15.5°E long
16	Apollo-17 1972 96 A USA	7 Dec 1972	11 Dec 1972	Southwest of Littrow Crater	20.2°N lat 30.7°E long
17	Luna-21 1973 01 A USSR	8 Jan 1973	16 Jan 1973	Eastern edge of Sea of Serenity, Lemonnier Crater	25.85°N lat 30.45°E long

The work program of Lunakhod-2 was very many-sided. Its main scientific task was a combined study of variation of the basic physical-chemical properties of the surface, as a function of the selenological-morphological situation, in the zone of transition of a mare region of the moon to the highlands. It was necessary to obtain selenological-morphological and topographical data, study the local magnetic situation, the chemical composition of the surface layer and the physical-mechanical properties of the soil, as well as the optical properties of the surface. To resolve these tasks, a magnetometer, RIFMA X-ray spectral apparatus and apparatus for evaluation of the physical-mechanical properties of the soil were installed on Lunakhod-2. Special phototelemetric markers were introduced into the field of view of the telephotometers. The selenological-morphological and topographical studies of the terrain were accomplished, on the basis of photography of the lunar landscape, which included obtaining television panoramas and photographs, as well as data on the distance travelled and position of the craft on /11 the lunar surface.

In distinction from Lunakhod-1, a number of new instruments, intended for solution of scientifically and technically interesting problems, were installed aboard Lunakhod-2. In particular, an astrophotometer, measuring the luminance of the lunar sky, a radiometer, measuring the characteristics of cosmic radiation and a Rubin-1 photoreceiver, used for conducting Lunakhod laser direction finding experiments, were installed. Moreover, the French laser corner reflector was again installed on Lunakhod-2. The laser direction finding and laser location experiments were carried out, for the purpose of precisely defining the coordinates of Lunakhod and its position, relative to elements of the surrounding relief, as well as parameters of the moon itself.

The capabilities of the RIFMA apparatus installed on Lunakhod-2 were significantly expanded over those of the Lunakhod-1 apparatus.

This increased the effectiveness of study of the chemical composition of the lunar soil. Together with this, changes and improvements were incorporated in a number of other Lunakhod-2 systems. The transmission frequency of the television images transmitted by the course television cameras was increased, and the height of installation of one of the cameras was increased. The images received became clearer. The mobility and maneuverability of the self-propelled vehicle was increased.

CHARACTERISTICS OF OPERATION OF LUNAKHOD-2

The Lunakhod-2 self-propelled, automatic vehicle handled the /12 work with which it was entrusted in an excellent manner. The crew, which, remaining on earth, knew how to control it, earned much merit in this case. Yes, the automatic lunar machine had its crew. These were the navigator, driver, flight engineer, operator and commander. They controlled Lunakhod clearly and in a well-coordinated manner and, together with them, representatives of the medical service stood watch. They continuously monitored the physical and psychological condition of the crew members, evaluating the level of their neuro-emotional stress. The effectiveness of the work of Lunakhod-2 depended greatly on the condition of the crew. Therefore, the medical men followed the state of the visual and motor analyzers, by means of special apparatus, and they also evaluated the leading psychic functions, memory, attention, thinking. The fact that the crew changed every 2 hours indicates the intensity of their work. By means of television pictures received from Lunakhod, the crew members had to know how to determine the distances to obstacles and the sizes of rocks and craters, as precisely as possible. They had to have well developed ideas of space (to see the "flat" images in the television pictures three-dimensionally). They had to have a good visual memory, correct and logical thinking etc.

The effectiveness of control of Lunakhod-2 increased significantly over that of Lunakhod-1. The matter here was not only the experience acquired by the crew, but the fact that the builders of the craft studied their requests and incorporated the necessary improvements into Lunakhod and its systems. This is why Lunakhod-2 travelled 37 km during its work, while Lunakhod-1 only travelled 10.5 km. However, the scientific value of the work of the Lunakhod on the surface of the moon, of course, is evaluated, not only and not so much, by solution of the problem of movement. A set of scientific instruments was installed on the vehicle, which worked according to a previously planned program. They delivered information by command from earth. However, a situation frequently developed in a current session when objects or parts of the surface appeared in the field of view of Lunakhod, which were of unexpected interest /13 to selenologists. In this case, the crew commander had to make the correct operational decision. Thus, he always thought under tension, considering the purpose and tasks of the present session, determining the time for conduct of an experiment arising unexpectedly, evaluating the condition of the onboard systems and their temperature conditions, the sun height in the lunar sky and the energy reserve aboard Lunakhod, and the time of setting of the moon beyond the horizon of the earth in the area of the remote space communications center and other factors. In distinction from Lunakhod-1, Lunakhod-2 and its crew learned how to accomplish turns in motion, which significantly improved the dynamic maneuverability. This also was facilitated by the fact that a so-called rugged television camera, raised above the body of the machine, was installed on Lunakhod-2. The fact is, that both television eyes of Lunakhod-1 were located below and surveyed the terrain from the height of a squatting man. Now, by means of the "upper" television camera, the driver can look ahead, like a man standing at full height. Therefore, he sees the rocks, craters and other obstacles encountered en route better.

Thus, the Lunakhod came down from the landing platform onto the surface of the moon. After checking out all onboard systems, the self-propelled behicle began to move. It photographed a panorama of the terrain, with a large crater, on the edge of which the landing platform had descended. Then, deploying, it went to the southeast.

PRELIMINARY RESULTS

During the first lunar day, Lunakhod-2 moved almost a kilometer away from the landing site. It then continued to move to the southeast and south, leaving the area of typical mare character and going into the hilly highland foothill zone.

It must be noted that the Sea of Serenity, on the eastern edge of which Lunakhod-2 began to operate, is an extensive lava plain, the surface of which, in distinction from those of the other circular mare, is not complicated by large craters. Within the mare section, the movement of the Lunakhod on its route encountered such relief forms as small craters and, in isolated cases, the scatter- /14
ings of rocks accompanying them. Fresh craters were encountered more rarely. Ancient, strongly smooth ones were encountered most often.

The relative number of so-called secondary craters, formed as a result of the impact of ejecta from the larger craters, was successfully estimated along the course of movement. Secondary craters, with sizes of from 0.5 to 2 m, turned out to be only 0.25% of the total number of craters. The thickness of the upper layer of the surface (regolith), which varied from 1 to 6 m, was successfully estimated.

Moving further along the hilly highland foothill zone, the Lunakhod reached the outer slope of the wall of a 2-km crater. Slide terraces, 10-15 m in extent, were found. The density of small craters decreased 2-3 fold from the "mare" density. The thickness of the regolith began to reach 10 m in places. Continuing to move to the east, Lunakhod reached Round Bay. This was the name given to a small bay on the southern edge of Lemonnier Crater, located approximately 15 km southeast of the landing point of Luna-21. Slide phenomena also were found in this area. Upon approaching the main part of the highlands in the Round Bay area, formations were noted on slopes of up to 17°, in the form of terraces, extending several hundred meters.

Moving further to the east, Lunakhod-2 came to an interesting tectonic fracture called Straight Rille. It has been determined that the length of the rille is 15-16 km and its depth, 40-80 m. Such tectonic fractures are evidence of displacements of large sections of the crust of the moon taking place in the past. On the moon (owing to the practical absence of erosion), tectonic fractures are preserved for billions of years and make it possible to observe the vertical cross section of the rock.

Approaching Straight Rille, a decrease in thickness of the regolith was noted and, on the lip of the fracture, the rock base was exposed, in the form of a rock "limb," which was noted over the entire extent of the part of the rille examined. The rock fragments were 1-2 m in size. Beyond the "limb," the steepness of the rille /15 wall was 30-35° and its slopes were covered with talus, consisting of large blocks and rocks. Thus, Lunakhod-2 established the location of an outcrop of bedrock several tens of meters thick.

When approaching the rille at various sections of it, the Lunakhod magnetometer recorded an increase in magnetic field strength. This apparently is evidence of the connection of the inherent magnetic field of the moon with surface structures. As Adacemician A. P. Vinogradov notes, the origin of this residual magnetism of the rocks of the moon is of cardinal importance, a key for explanation of the history of the moon in space.

Over the entire course of Lunakhod, study of the soil structure, its mechanical characteristics and finding and study of irregularities in the structure of the upper layer were carried out systematically, and the interconnection of the physical-mechanical properties of the soil with the selenological-morphological features of the terrain were determined. Individual formations were studied in greater detail.

Analysis demonstrated that the structure of the upper layer of the soil corresponds to that of a fine-grained material, having appreciable adhesion. The mechanical properties of the soil on the course changed within broad limits. Thus, the carrying power varied from 0.1 to 1.5 kg/cm^2. Sections of the surface were found, with a small layer of loose material on a solid base.

In modernization of the RIFMA apparatus installed aboard Lunakhod-2, particular attention was given to more accurate determination of the iron content. The fact is that the content of it in the highland soil is less than in the mare. Therefore, in study of the mare-highland transition zone, the iron content had to be traced more precisely, and the ratio of the content of iron to that of other elements (for example, aluminum) had to be determined.

Next to the descent stage, the measurements gave the following results: iron content 6 ± 0.6%, aluminum 9 ± 1%. It is interesting that measurements made by Lunakhod-1 in the Sea of Rains gave an iron content of 10-12%. Subsequently, during movement of Lunakhod-2 to /16 the hills, the iron content began to decrease and, at a distance of 5 km from the landing point, it was 4.9 ± 0.4%. The lowest value was 4.0 ± 0.4% (the aluminum content increased to 11.5 ± 1.0%, in this case).

Moving along the planned course, the Lunakhod crossed a region with different reflecting properties (albedo). The type of rock can be decided indirectly from this data. By means of comparative analysis, these data obtained by Lunakhod-2 can be used for identification of the type of rock in the most diverse areas of the moon.

Besides study of the magnetism next to Straight Rille, which has already been mentioned, magnetic measurements were carried out in other sections of the area studied. A three-component ferromagnetic magnetometer was used for this purpose. Magnetic measurements were made, both while moving and at stops. It can be noted from the data obtained that the magnetic field on the surface of the moon is very irregular. Anomalies in distribution of the field were noted at all craters along the course. Characteristic changes in the field were noted at the stops, which indicate current induction processes in the body of the moon, due to the changing external fields.

Interesting laser direction finding experiments were conducted, using the Rubin-1 photoreceiver installed aboard the Lunakhod.

Optical quantum generators (lasers), located at the high mountain observatory of the P. K. Shternberg State Astronomical Institute, in the mountains of the Zailiyskiy Alatau, near the city of Alma-Ata, and at other points in the Soviet Union, sent a light pulse to the Lunakhod, which was received by Rubin-1 and retransmitted to earth by radio. About 4000 hits of the laser beam were recorded in the Rubin-1 photoreceiver, and over 1500 photographs of the moon were obtained, with laser beam direction markers, for measurement of the selenographic coordinates of the Lunakhod. This permitted determination of the Lunakhod coordinates with high accuracy, independently of other methods of measurement.

As has already been stated, a lensless electron telescope, the /17
astrophotometer, was installed aboard Lunakhod-2. The instrument was intended for receiving both radiation visible to the eyes and near ultraviolet radiation, for which there were two channels in it.

Three main problems were solved by use of this instrument. First, the illumination of the night sky on the moon was determined, which is very imporant for understanding the possibilities of conducting astronomical observations from the surface of the moon. Second, the zodiac light of the sky was studied (the zodiac light phenomenon is formed, owing to scattering of solar radiation by meteor particles). The possibility of study of the zodiac light at very close distances from the sun is allowed by Lunakhod. This is inaccessible to observers from the earth. The third problem was to determine the spectral composition of our galazy (the Milky Way) and the star fields surrounding it.

The astrophotometer was switched on 14 times, during the period of operation of Lunakhod-2. This permitted measurement of the brightness of the lunar sky. Analysis of the data obtained showed that the brightness of the visible rays of the daylight and "twilight" (after setting of the sun below the local horizon) of the sky of the moon proved to be unexpectedly high. The data obtained indicate that this brightness is 10-15 times greater than the luminance of bright sections of the night sky, observed from the surface of the earth. Simultaneous with this, the luminance of the night sky in the ultraviolet region of the spectrum was measured by the other channel. It turned out to be low and only a little greater than that, which was observed from the Kosmos-51 and Kosmos-213 earth satellites on the night side of the earth. Subsequently, these data will be refined, but what has been obtained indicates that the moon is surrounded by a layer of dust particles, which strongly scatter visible sunlight and light from the earth.

Measurements also were made in the deep lunar night. In this case, the astrophotometer was aimed at the local zenith, and it could not see dust illuminated by the sun. It turned out that the night brightness of the lunar sky is only a little greater or the same as the sky brightness measured by satellites in circumterrestrial space on the dark side of the earth.

Thus, the data obtained indicate that the sky above the moon /18 is sufficiently "dark," to conduct ultraviolet astronomical observations from its surface, both by day and by night. Concerning observations in the visible range, the conditions change significantly from day to night. These data are of great importance for future conquest of the moon and its use as the location for deployment of astronomical observatories.

PROSPECTS OF CONQUEST OF THE MOON

The era of study of the moon by means of spacecraft began in 1959. We have learned a great deal of important information about our natural satellite since that time. We know now that there is practically no atmosphere or magnetic field on the moon, and we know the physical-mechanical characteristics and chemical composition of the lunar soil, in different areas of it. Experience has been obtained in movement of astronauts and automatic self-propelled vehicles on the surface of the moon.

The natural question arises: And what are the future aspirations of man, with respect to the moon? Will it become only a magnificent scientific base of mankind, or will it be the location of development of a space economy, with a developed rock extraction industry and large energy systems, to which the most harmful types of industries will be moved in time from the earth?

It seems to us that the future of the moon is that of a complex scientific base, for many-sided selenological-morphological, astrophysical, physical, chemical, biomedical and other studies (primarily in the first stage of its conquest) and an outpost in the settlement of mankind in the spaciousness of the universe. In our opinion, precisely this heavenly body will be transformed by the projects of man, for his settlement and comprehensive economic use.

How will this take place? Two ways can be contemplated. One of them consists of use of the naturally occurring conditions on the moon, for construction of complex technical and residential buildings on its surface, conforming to the relief and soil, as well /19 as recovery of the mineral resources necessary for the lunar settlements. This way of conquest and colonization of the moon has already been described in diverse literature. However, it seems to us that a more basic transformation of lunar conditions on a global scale is rational, for the purpose of transforming it in the future into a heavenly body adapted for the life and activity of man.

What is this needed for? Although we still do not know completely today all the delicate problems connected with creation of normal conditions for the biosphere, we already know a number of fundamental, key questions. We know, for example, that a magnetic field with specific characteristics (we have just such a field on earth) is necessary for normal existence of life. Besides this, the corresponding radiation situation should be provided, which is not injurious to living matter. Such a situation is created on our planet, first, by the geomagnetic field, which shields the surface of the earth, forming a captured radiation zone (the so-called radiation belts of the earth, first discovered from artificial satellites) and, second, an atmosphere which is a powerful shield, preventing destructive radiation from passing through to the surface. Together with this, the importance of an atmosphere having completely specified characteristics for respiration of living organisms is well known. It is an indispensible condition for the existence of the biosphere. All these and a number of other features, under which life arose and developed on earth, are conditions for its existence. These conditions are not only necessary, but convenient for the life and activity of man. Of course, the same conditions could be created in some limited spaces, for example, in the interior spaces of the lunar base (they will be established without fail), but this does not exhaust all the requirements of man in comprehensive conquest and use of the moon and global settling of it.

It seems to us that the natural conditions on our natural satellite should approximate those of earth. An atmosphere should be created there, the molecular weight of which, however, should be greater than that of the air to which we are accustomed. This is /20 explained by the fact that a heavier atmosphere will dissipate into space at a lower rate, under the conditions of the significantly lower gravitational potential of the moon than that of the earth, and that "make-up" of it will be a completely practicable technical matter. Finally, an atmosphere can be created, which will not remove the necessity for working in space suits, but it will be easier and space suits more convenient, not interfering with the activity of the man, which cannot be done successfully when there is no atmosphere on the moon. Moreover, the atmosphere becomes a good "armor" shield, which protects the surface of the moon from cosmic radiation and solar flare radiation.

An artificially created magnetic field of the moon, the characteristics of which will be selected in such a way as to create the most reasonable conditions for life on the surface, will serve this same purpose.

Despite the seemingly fantastic nature of it, all this is completely practicable, even with the present technical capabilities. Creation of a favorable radiation and magnetic situation and atmosphere will bring unique lunar flora to life and lead ultimately to the appearance of a unique biosphere on the moon, which will make it a tiny planet of life, on the way to the settlement of mankind in the unlimited spaces of the universe.

In this respect, the moon is beginning to lose its importance as an outpost of science, having favorable conditions for astrophysical and other studies. It will be transformed, as it were, into a seventh continent of our planet, on which people will have all the conditions for work and life. The scientific stations basically will migrate to the satellites of other planets (for example, Jupiter, Saturn, etc.). The moon will become economically one of the most developed areas of the earth-moon system, relieving our planet of energy-consuming industries. Part of the space economy of earth, moved to our natural satellite, will encompass recovery of mineral resources, production of nuclear fuel for prospective rocket systems sent from lunar spaceports to remote space. Powerful radioengineering installations, intended for communications with interplanetary stations and, possibly, with other civilizations, will be located /21 on the moon. The mining industry of the moon will not only satisfy its needs, but will supply the earth with rare elements. The presence of six times less gravity on our natural satellite will permit production of large crystals, optical mirrors, medical and chemical preparations of increased purity, in manufacture of which, the terrestrial force of gravity interferes significantly. This circumstance will be extensively used in specialization of the future lunar industries.

The future moon possibly will turn out this way, but, on the way to it, we still have much to learn of our natural satellite, of the earth and of the solar system overall, and we have to thoroughly study the moon and circumlunar space. These problems are being solved successfully by Soviet automatic vehicles, one of which, Lunakhod-2, gave science a great amount of diverse information on the moon. The data received from the Lunakhod also is of great importance, in development of ideas of the history of earth, primarily of the first billion years of life as a planet. Such are the laws of science -- far into the ages, for the sake of the space future of mankind.

N75 22258

Mutual Assistance in Space

K. Bushuev

One of the major achievements of space technology in recent /22 years is solution of the problem of docking spacecraft. Scientists and engineers, both here and in the USA, have worked hard and continue to work on this problem, and spacecraft now dock in space.

The first experimental manned orbital station was created in our country, as a result of docking of the Soyuz-4 and Soyuz-5 spacecraft in orbit, in January 1969. The first long-term orbital station in the world, Salyut, was injected into earth orbit in April 1971. In June of the same year, the transport Soyuz-11 docked with Salyut and delivered a crew to the station. One cannot do without docking in space during flights of man to the moon. The flight program of the American Apollo spacecraft, as is well-known, included a docking operation, on the way from the earth to the moon and in selenocentric orbit, after launching the ascent stage of the lunar craft from the moon.

DOCKING IN FUTURE SPACE FLIGHTS

Further development of space flights is inseparably connected with docking technology. Without it, for example, creation of large orbital complexes in circumterrestrial space, for solution of various scientific and national economy tasks, is impossible. The framework of such complexes will be multipurpose orbital stations, consisting of units for different purposes. These units will be delivered into orbit by rockets and reusable spacecraft, and they will be replaced by new ones as they complete their tasks. The /23 delivery and exchange of crews maintaining the space stations will be accomplished by the same method.

Multipurpose prefabricated orbital stations will become bases in the future, from which manned spacecraft and unmanned vehicles can be launched, for example, to the planets of the solar system. The craft will return to the base, delivering research material obtained in flight there: photographic and motion picture documents, samples of rock, measurement data, etc. Exchange of crews, refueling and resupplying life support resources, replacement of equipment and performance of preventive maintenance work will take place on t e bases. Of course, all these operations require repeated execution of the approach and docking operations in space.

It is difficult to imagine an expedition of people to the planets of the solar system, without docking, not only around earth, but around the planet itself. The programs of such expeditions will obviously provide for creation of base stations in orbit around a planet. Flignts to the surface of the planet, of both automatic probes and of spacecraft with crews, will be accomplished from this base, and 'hey will return to the orbital base after completion of the research program. The spacecraft with the astronauts will be launched toward earth from this base. All this is organically involved with execution of approach and docking operations of automatic and manned spacecraft.

Finally, assisting a spacecraft suffering a disaster also is impossible, without a second craft, coming to its assistance, approaching and docking with it.

Questions of space flight safety have been the center of attention of scientists an' engineers, from the very start of working out this most complex scientific and technical problem. A spacecraft and its systems undergo comprehensive experimental development on earth. Redundancy (duplicating, triplicating) of not only individual elements of it but of the entire system, is extensively used in the set of spacecraft onboard systems. Such a reliable method

of triplication as "automatic voting," when three parallel output /24
signals or commands, generated by elements of the same type, are compared and subsequent actions are taken, with coincidence of at least two signals (commands). Such a scheme ensures reliable operation during a failure or incorrect functioning of any of the three elements.

However, despite all the measures taken, a situation, in which a spacecraft may need immediate assistance, cannot be excluded from consideration.

It is expected that the greatest space activity of man in the coming years will take place in circumterrestrial space. Such flights are now the most timely ones, since they permit solution of a number of important practical problems, which are useful for the terrestrial activities of man in the most diverse fields. It cannot be doubted that the time is near, when flights of manned spacecraft and orbital stations in circumterrestrial space, both here and in the USA and, in the future, in other countries, will become an ordinary matter. Such flights will be accomplished more and more often, and larger and larger numbers of people will participate in them. In the same way as, for example, took place before our eyes with aviation flights, which were the privilege of a few daredevils a few decades ago.

Expansion of the scale of space flights undoubtedly will be accompanied by improvements in space technology and an increase in its reliability. However, with an increase in number of space flights, the probability will increase that individual space flights, because of some trouble, will turn out to be in a position, in which it will be difficult or even impossible to ensure the safety of a crew with their own resources. This may take place, for example, with failure of equipment, by means of which braking of the craft is accomplished, for descent from orbit and landing on earth. In such cases, it may prove to be necessary to provide outside help to the craft in distress. Assistance has to be given to that spacecraft, regardless of its national affiliation, which can be given to it most rapidly by others. For example, a craft already in orbit or standing on earth, in a state of maximum readiness for flight.

A similar arrangements has existed long since on the seas and oceans. It is sufficient for a crew in distress to transmit the SOS signal by radio, and each vessel located close by, performing its duty, hurries to its aid. Unfortunately, introduction of a similar arrangement in space encounters great technical difficulties, flowing from a complicated problem. Mutual assistance in space is practically impossible, if the craft is not equipped with the necessary resources for search, approach and docking, if it is impossible to transfer from one craft to the other, in order to provide technical assistance or, if necessary, to transfer the crew to it. /25

An effort to establish a technical foundation for mutual assistance systems in space was one of the main reasons for the signing of an agreement between the governments of the USSR and USA on 24 May 1972, in which the parties pledged themselves to jointly develop compatible spacecraft and station approach and docking facilities. As the first experimental stage, this agreement specifies accomplishment of an approach, docking and joint flight of a Soviet Soyuz spacecraft and an American Apollo spacecraft in 1975. The flight program also includes transfer of crews from one spacecraft to the other.

The signing of this agreement was preceded by a series of meeting of Soviet and American specialists (they began in 1970), in which the principles of cooperation of the Soviet Union and the USA in solution of the technical problems, connected with the docking of Soviet and American spacecraft and stations, were worked out. Several working groups were established, for work on various aspects of this complicated technical task. They met repeatedly, for discussion of principles and specific proposals to create joint systems, permitting docking and transfer from spacecraft to spacecraft.

THREE CONDITIONS OF COMPATIBILITY

What is understood by the principle of compatibility of spacecraft approach and docking systems?

In order for each craft, in case of need, to be able to approach and dock with any other craft or orbital station, satisfaction of three basic conditions is necessary. /26

The first condition is compatibility of the docking units, i.e., all devices which join directly in docking. Moreover, the design and automation of each docking unit must be such, that this unit can perform all necessary functions in the active or passive craft (the docking units must be active-passive general-purpose or, as now is customarily said, androgynous): each spacecraft may turn out to be in a position of expecting assistance and in the role of coming to assistance.

The active and passive spacecraft have completely different docking unit designs at the present time, for example, the probe with grapples on the active craft and the receiving cone on the passive one. The necessity flows from this of creating fundamentally new androgynous docking units, permitting each of the craft to perform the role of both active and passive object in docking.

The second condition is compatibility of facilities, providing for search and approach of the craft. The active craft, using radio-engineering or optical resources, must find (of course, with the assistance of the ground services) the passive craft and approach it.

The control engine system of the active craft permits it to maneuver by changing all six coordinates of its position (three coordinates of the center of mass and three of the angles) and the corresponding velocity components. As a result of maneuvering, the active craft must approach the passive one, with a given accuracy of all relative velocities and mutual position parameters in space and ultimately ensure mechanical contact of the docking units of both craft.

As a rule, the passive craft assists the active craft in performing the search and approach, by means of its radio system. In some cases, the passive craft executes a limited maneuver, on command from the active craft or earth. Of course, it can happen that the craft in distress will lose the capability of maneuvering. In this case, it will be simply a body occupying an arbitrary position in space, in the orbital coordinate system. /27

The radio systems of both craft operate jointly in the search and approach. For this, they have to be built on identical principles. Unified methods of measurement of the parameters of relative movement, the same type of modulation, matched frequencies and other signal parameters, matched transmitter power, receiver sensitivity, antenna direction patterns and other characteristics, have to be used in them.

In the future, evidently, one has to strive for the capability of performing search and approach to a craft, without creating any radio radiation, since the case cannot be excluded, when the onboard radio system of a craft is damaged, and the rescue craft has to find it, by using only radar and optical search and guidance means. In particular, unification of a number of elements, providing for optical measurements (unification of the optical targets on the craft, matching of the light reflection and absorption coefficients of the surfaces of the craft) and use of optical measuring devices with unified characteristics are necessary for this. In order to facilitate visual detection of a craft and determination of its position in space, the craft have to be equipped with unified pulse beacons and mutual orientation light signal systems. Radio communications must also be provided between the craft, in the search and approach process.

Finally, the third condition of compatability is that the spacecraft atmosphere parameters, in particular, their composition and pressure, must be matched. This condition does not require special explanation. It is clear that, even after the craft have docked, the astronauts cannot transfer from one to the other, if the craft have significantly different atmospheres. In this case, special transfer sections and unique air locks are necessary as a minimum and, depending on how much the atmosphere parameters differ, prolonged (for several hours) "acclimatization" of the astronauts in the transfer section may be necessary. This, in turn, in some cases, bring the entire operation of giving assistance to the spacecraft /28
crew to naught.

This is why it is necessary that the atmosphere parameters of various craft be close to each other. In this case, the principles of conditioning the atmospheres inside the craft do not have to be identical without fail.

How is it proposed to satisfy these three conditions of compatibility, for accomplishment of the joint flight of the Soyuz and Apollo spacecraft?

When the proposal was advanced to accomplish the program of docking these craft as the first, experimental stage, the conditions for compatibility of their construction had to be analyzed, first and foremost. In discussion of this problem, it became clear that the Soyuz and Apollo craft do not satisfy a single one of the conditions of compatibility.

This is not surprising. The craft were built in different countries, development was carried out separately and, of course, there were no mutual contacts between the developers. Much different principles were embedded in the designs of the craft and equipment, and neither side had mutual docking of them in mind, in developing their spacecraft.

Therefore, the problem of preparing the Soyuz and Apollo spacecraft for execution of the approach, docking and joint flight program turned out to be quite complicated, and solution of it requires great efforts, on both our and the American sides.

Let us examine, in the most general outlines, how the incompatibility of the Soyuz and Apollo spacecraft is specifically expressed and what has to be done, in order to provide this compatibility.

COMPATIBILITY OF DOCKING UNITS

Existing designs of ours and the American docking units differ so much, that mutual docking of the craft is completely excluded and no half measures can solve the problem. Joint working up of the docking unit designs showed that not a one of the existing versions can be used as the basis. This is primarily because both docking /29 units are not of an androgynous design. The docking assemblies of both the Soyuz and Apollo are made by the "probe-cone" system.

The Soviet and American designers had to develop the design of a completely new, completely compatible, androgynous docking unit, with peripheral catches, which can be used in both the Soyuz and Apollo. Models of this unit, on a 1:2.5 scale were fabricated here and in the USA. They passed laboratory testing in December 1972, during a joint meeting of Soviet and American specialists in Moscow. Much work in experimental working out of the design and automation, on full-scale models, now stands ahead.

COMPATIBILITY OF ATMOSPHERIC PARAMETERS

The Soyuz and Apollo spacecraft have different atmospheric parameters. In the Soyuz, it is practically the same as the terrestrial atmosphere to which we are accustomed: pressure 760 mmHg, oxygen content 17-33%, nitrogen 66-82%.

An atmosphere with 100% oxygen content and a pressure of 260 mmHg is used in the Apollo. Such a low pressure is possible, only with a pure oxygen atmosphere.

The existing differences in the atmospheric parameters practically do not allow opening the transfer hatches after docking of the craft and transferring the volumes of the living sections between them. It also is impossible to accomplish a sufficiently rapid transfer of the crew members from one craft to the other. The Apollo crew cannot transfer to Soyuz, without passing through a slow, gradual increase in pressure. Direct transfer from Soyuz to Apollo, from an atmosphere with a nitrogen content, to a pure oxygen atmosphere with a low pressure is not permissible at all. It would lead to an abrupt release of nitrogen and carbon dioxide dissolved in the blood, which can lead to embolisms in the blood vessels. A process of desaturation is necessary for a transfer to the oxygen atmosphere of Apollo, in which the astronaut puts on a mask /30
and breathes pure oxygen at quite high pressure. The process lasts from 2 to 5 hours and results in washing the nitrogen out of the blood.

It also is impossible to combine the Soyuz and Apollo atmospheres, because the conditioning systems in these craft are built on completely different principles. Continuous regeneration of the atmosphere takes place in Soyuz. Special devices absorb the carbon dioxide and give off pure oxygen, by means of decomposition of alkali metal compounds. The rate of this process is regulated by automatic devices, which control the composition of the atmosphere.

In Apollo, absorption of carbon dioxide is accomplished with non-regenerative absorbers, and the required oxygen content is maintained with an onboard supply in cylinders.

Combining the atmospheres of the craft, with such different conditioning systems, would lead to disruption of the automatic devices of these systems, to disruption of their normal operation.

For the joint Soyuz-Apollo flight, it is planned to create a special transition (docking) module, with an unusual airlock chamber, which turns out to be located between the inhabited sections of the craft after docking, in the path of the astronauts from one craft to the other.

The transition module developed is a component part (section) of the Apollo craft, and it is injected into orbit together with it. In order to transfer, for example, from Soyuz to Apollo, the astronaut opens the hatch to the transition module, in which an atmosphere corresponding to the Soyuz atmosphere is established at this time. In this case, of course, the hatch on the Apollo side of the module is closed. The astronaut then enters the transition module, closes the hatch and goes through the desaturation process. The pressure in the transition module is gradually reduced and the oxygen percentage content is increased. At the end of desaturation in the transition module, a pure oxygen environment is established, at a pressure of 260 mmHg. The astronaut is ready to transfer to the Apollo.

The reverse transfer also takes place through the airlock /31
chamber (transition module), and it also is accompanied by gradual change in the parameters of its atmosphere.

As has already been stated, desaturation is a long process. In point of fact, it excludes a rapid transfer from craft to craft. Desaturation can only be avoided and the transfer problem solved radically, by means of approaching the parameters of the atmosphere of one of the craft, for example, by means of reducing the rated pressure in the Soyuz sections. The fact is that, in the transfer of an astronaut to a pure oxygen atmosphere, with a pressure of approximately 260 mmHg, the nitrogen dissolved in his body, at a pressure of not over 500 mmHg, presents no danger. In this case, the desaturation process can be given up. This version, although it involves a number of difficulties and inconveniences, is considered to be the primary one in the joint Soyuz and Apollo flight project.

COMPATIBILITY OF APPROACH SYSTEMS

At the present time, each of the craft, the Soyuz and the Apollo, have their radio systems, for determination of the relative position and mutual movement parameters. The characteristics of these radio systems, in particular, the characteristics of the information used in them, differ significantly. In the joint experimental flight, it has been decided to carry out the search and measurement of the relative movement parameters (radial velocity and distance), by means of the Apollo radio system, which will take the part of the active craft. The answering part of the Apollo radio system, a transponder, will be installed in the Soyuz. Together with this, an optical system will be used, by means of which the Apollo crew can observe Soyuz from a distance of several hundred kilometers during the approach, and also determine the angular position of the line of vision. For optical measurements in the dark (from a distance of several tens of kilometers), pulsed light beacons are being installed on the Soyuz. In the final section of the approach, the exact mutual position of the craft is determined /32
visually, by means of an Apollo optical instrument, and the onboard orientation lights and special docking target on the Soyuz.

All measurement information will be fed into the onboard computer, which will give the recommendations necessary for control of the craft.

THE PROBLEM OF ORGANIZATION COMPATIBILITY

The joint Soyuz-Apollo flight is the first practical working out of elements of a possible system of mutual aid in space. It also requires much work on the part of flight control. Here to, there are problems of compatibility, of technical and organization compatibility.

A joint flight, mutual maneuvering and approach and docking of the craft are impossible without reliable radio communications between them and communications with ground tracking stations. In order to provide this communications, additional radio systems will be installed aboard Soyuz and Apollo, which work on the frequencies adopted by both the Soviet and the American sides. Control of the flight of the craft and their docking in orbit are very complicated processes. A large number of measuring points, scattered almost everywhere over the earth, several computer facilities and technical facilities connected together in a complicated way, and many qualified specialists participate in them.

All necessary information, from news of the condition of the astronauts to the exact coordinates of the approaching craft, converges on the central flight control point, on this brain of the giant electronic space complex, through numerous communications channels. In performing the docking and the joint flight of the Soyuz and Apollo spacecraft, reliable, multi-channel communications and clear interaction of the Soviet and American ground command-measuring facilities and flight control centers are required. All this requires solution of a number of new and quite complicated technical and organizational problems.

The Soviet and American specialists are jointly working out a detailed flight program now. Special training of the crews, their conditioning and familiarization with individual elements of the equipment of the other craft will also be important tasks. /33

Much work is connected with working out joint methods of the so-called ballistic security of the flight. This can include the unified models of the atmosphere and gravitational field of the earth adopted, matched coordinate systems, matching of requirements, terms and definitions, which have been adopted in each country and which do not always coincide.

In this sense, for example, the fact that the metric system of units has been adopted at NASA, while the transition to the metric system still has not been carried out in the USA on a national scale, has simplified the work greatly.

DOCKING TECHNOLOGY

Whatever version of the docking devices of the spacecraft are made, they are charged essentially with the same function. Docking devices must:

Provide the initial coupling of the craft;

Absorb the impact energy;

Carry out alignment of the craft (docking of spacecraft takes place, as a rule, with some mismatch in their mutual positions);

Draw the craft together and ultimately ensure rigid and sealed joining of them;

Provide for undocking the craft, after completion of the joint flight.

All devices, by means of which docking of spacecraft has been carried out up to the present time, have been made by the "probe-cone" system. The Soyuz-4 and Soyuz-5 spacecraft, as well as the Soyuz-11 spacecraft and the Salyut orbital station, dock by this method. Docking of the spacecraft in the Apollo program was accomplished by essentially the same method.

In the "probe-cone" system, the active docking unit ("probe") is installed on one of the craft and the passive ("cone"), on the other. /34 In distinction from this, the androgynous docking devices, which will be used in docking the Soyuz and Apollo in particular, permit either of them to participate in the docking, in the role of both active and passive spacecraft.

Let us examine the operation of a "probe-cone" type device, using the example of the docking of Soyuz-11 with the Salyut orbital station. Schematic outlines of the docking units of the Soyuz-11 spacecraft and the Salyut station are presented in Figs. 1 and 2.

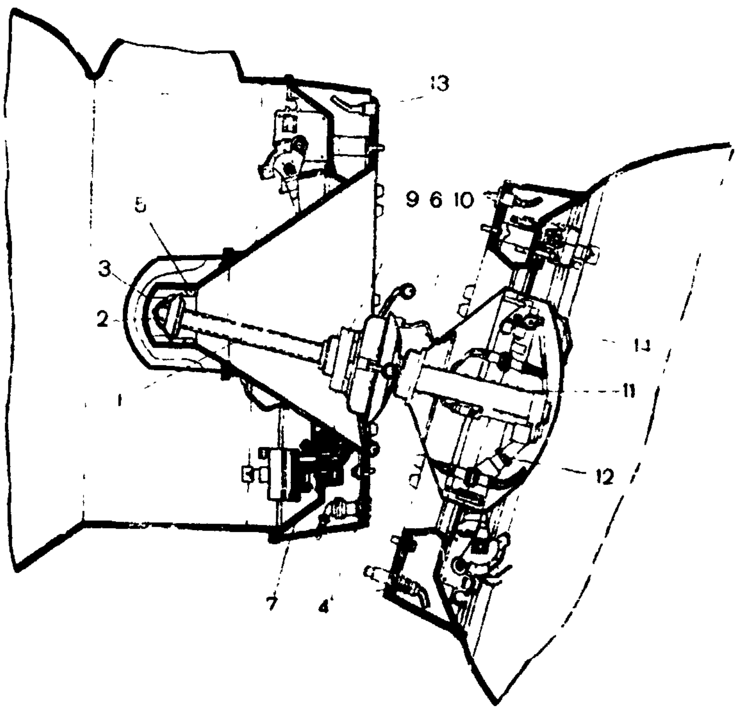

Fig. 1. Simplified drawing of docking device used during docking of Soyuz-11 and Salyut. The device is shown at the moment of coupling the craft: 1--rod; 2--rod head with catches; 3--receiving socket; 4--water connection; 5--stop; 6--alignment levers; 7--docking frame; 8--receiving cone; 9--electric drive; 10--ball joint; 11--guide rods; 12--lateral shock absorber; 13--electric connection; 14--electromechanical damper.

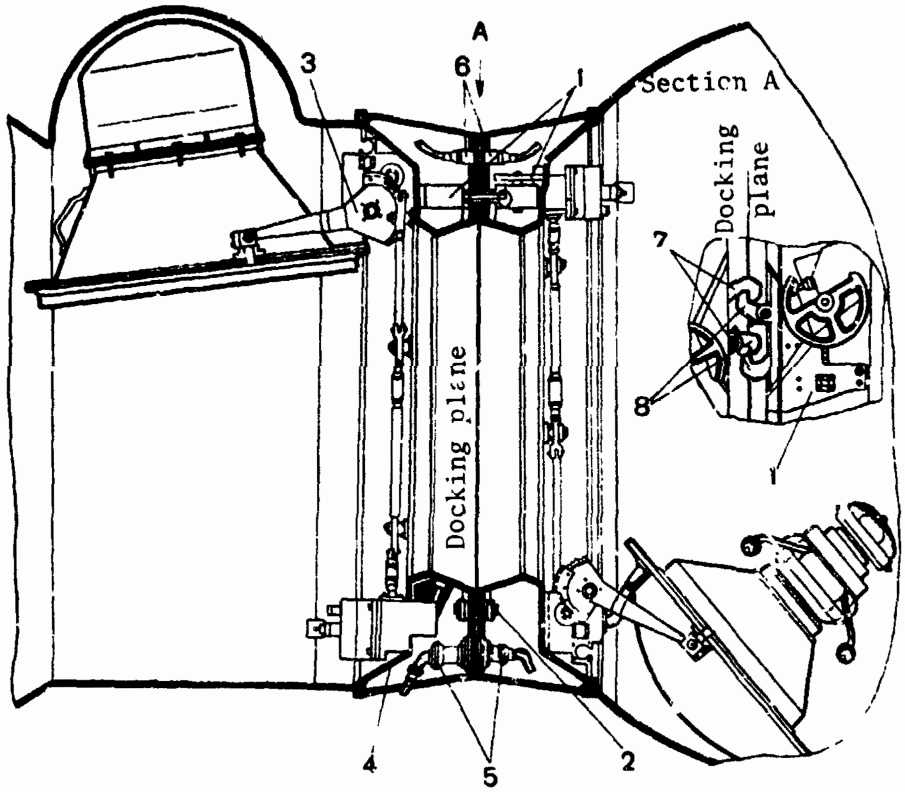

Fig. 2. Simplified sketch of docking device shown in Fig. 1; docking of craft has been completed, both covers have been folded back and the hatch-manhole has been formed: 1--peripheral lock; 2--docking seal; 3--hatch cover drive; 4--docking frame; 5--water connection; 6--electrical connection; 7--active hooks; 8--passive hooks.

The active craft, it was Soyuz-11, in this case was equipped with a telescopic rod (probe), which ended in a heat with catches. On the passive craft, on Salyut, there is a rec. ing cone, which ends in a receiving socket with catches. Docking of the craft begins with the rod entering the receiving cone and touching its walls (contact).

By inertia or using a low thrust engine, the active craft continues to approach the passive one. The head of the probe, sliding along the surface of the cone, enters the receiving socket and is secured there by the catches. Coupling of the craft takes place.

The electric drive then begins to pull in the probe and, together with this, the craft are drawn together, until the docking frames are in contact. In conclusion, by means of the peripheral locks, located on the docking plane, a rigid, sealed connection is formed.

Let us examine some of this sequence of operations in greater detail.

When, at the moment of making fast, the probe enters the receiving cone, as a rule, it strikes with its head (an exception would be the case of quite low probability, when the head enters the receiving socket exactly). The probe is displaced backwards by the impact, and it turns in the ball joint. The impact energy is absorbed by the damping system, which consists of spring shock absorbers and electromechanical dampers (Fig. 1).

We now look at what takes place, when the head of the telescoping probe enters the receiving socket, as a result of the continuing approach of the craft. The profile of the socket is such, that the /35 head catches are initially held down and then separate, entering the slots intended for them. In point of fact, coupling of the craft consists of this. Their mutual oscillations after coupling are restricted by special stops.

After the mutual oscillations are quieted down, the electric drive of the active coupling unit is switched on. By means of a ball-screw mechanism, it begins to pull in the probe. As the probe is pulled in, the head catches move in the opposite direction, in /36 the slots of the receiving socket, and they stop, upon reaching the stops. The slots in which the catches move gradually narrow and the initial banking mismatch of the craft is decreased by means of this.

After the head catches contact the socket stops, pulling together of the craft begins. The probe continues to be pulled in, "to be shortened," and it simultaneously diverges in the direction of the alignment levers located on its base. Touching the walls of the receiving cone, they carry out the final alignment of the craft.

As the probe is pulled in further, the docking planes, those portions of the docking frame, by which the craft must be in contact with each other, approach. The hydraulic connection probe enters its receiving socket, and the electrical connection probe, its socket; this permits the craft to have a common hydraulic system and electric power supply system after docking. After the docking frames contact each other, the peripheral catches are triggered: the hooks of the active docking unit, turning, engage the hooks of the passive unit. The docking seal device, pulling the hooks together, pulls the docking planes together with a force of over 10 tons. Thus, a rigid, tight connection of the craft is ensured.

After the docking operation is completely finished, the receiving cone, located on the hatch cover of the passive craft, and the probe mechanism, located on the cover of the active craft, are opened inward, by means of special drives. A manhole-hatch is formed here between the craft (Fig. 2).

We note that, in the first docking of the Soyuz spacecraft, formation of a sealed hatch-manhole was not provided, and the astronauts transferred from one craft to the other by going through open space.

Now, to the arrangement of the androgynous docking units (Fig. 3).

The desigr of the units, intended for docking the Soyuz and Apollo spacecraft, is based on a mobile ring, with three guide projections. A major feature of the system is that this ring is hinged to six rods.

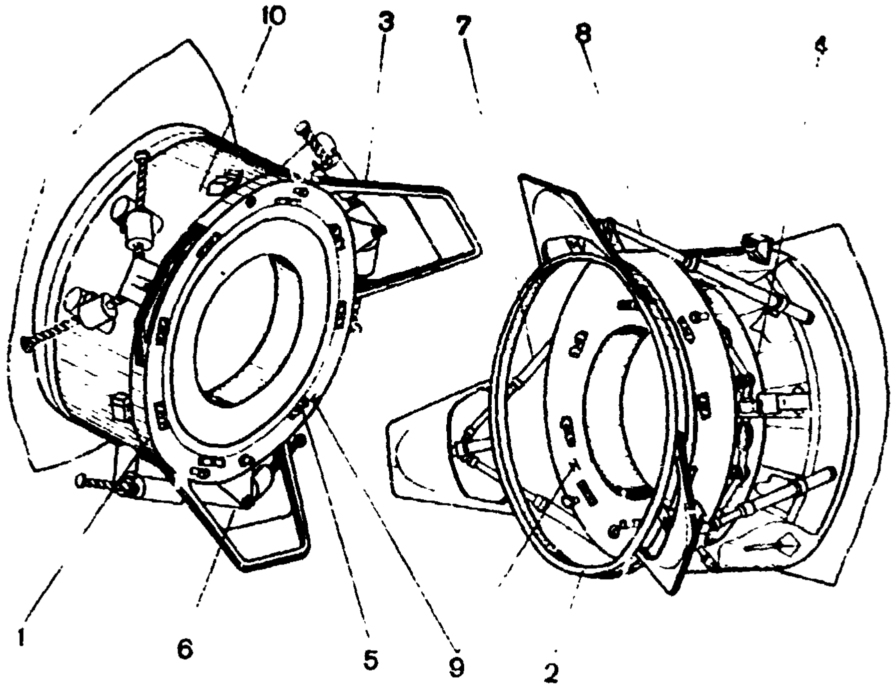

Fig. 3. Simplified sketch of androgynous docking device, developed for joint Soyuz-Apollo flight program: 1--ring of passive craft (retracted); 2--ring of active craft (extended); 3--guide projections; 4--docking frame; 5--docking frame catches; 6--ring catch; 7--ring securing rods; 8--shock absorbers; 9--docking planes; 10--catches on housing.

In the transport position (passive condition of the docking unit), the ring is retracted and is below the plane of the docking frame. The ring of the active docking unit is extended to the initial position for docking beforehand. The active craft moves in the mooring section, so that the guide projections of its ring go into the gaps between the guide projections of the ring of the second craft. The guide projections on the rings ("petals") have a trapezoidal shape. Therefore, after touching, which can take place with appreciable mismatch of the craft (just as in the "probe-cone" system), and during further approach of them, the mobile rings will be more and more exactly conjugated and finally coincide with one another. /39

Since the fastening rings on the mobile rods are hinged and the rods are capable of changing their length, the rings coincide, even in the event the axes of the craft do not coincide.

After precise coupling of the rings, the catches on the ring of the active docking unit engage the catches on the housing of the passive unit.

There are mechanisms in the docking unit, which return the ring of the active craft to the initial position. After joining, alignment of the craft takes place, by means of the energy, which accumulated in these mechanisms during the impact. Dampers quench the collision energy. The craft are pulled together, by means of drives, which change the length of the rods. In this case, the ring of the active docking unit is returned to its housing and contact of the planes of the docking frames occurs as a result, and the docking frame catches are triggered (they are similar to the catches in the "probe-cone" type docking units). The sealing mechanism, pulling the catch hooks together, ensures a rigid, tight connection of the craft. After this, the covers are folded back and a hatch-manhole is formed between the craft.

In a short article, we have succeeded in touching on only a few of the basic problems, connected with organization of mutual assistance in space. The actual group of basic problems is considerably more extensive, and these problems themselves, in a detailed examination of them, involve solution of a large number of scientific, technical and organizational problems. However, all these problems will undoubtedly be solved in one way or another and a technical foundation will be created, in this manner, for both mutual assistance in space and for accomplishment of joint flight programs of spacecraft of different countries. /40

N75 22259

Lunakhod-2: Preliminary Research Results

A. Vinogradov and S. Sokolov

In accordance with the program of investigation of the moon and the planets of the solar system, the unmanned spacecraft Luna-21 delivered the self-propelled vehicle Lunakhod-2 to the area of the eastern edge of the Sea of Serenity, on 16 January 1973, at 1:35 a.m. Moscow time. The unmanned craft completed a landing inside an ancient 55-km crater, named for the 18th century French astronomer Lemonnier. The landing point of the craft, located near the southern edge of Lemonnier crater, has the coordinates 30°27'E longitude and 25°51'N latitude. /41

Until recently, study of the surface of the moon has been limited to either "mare" or "highland" areas. Study of the properties of the lunar surface in the "mare-highland" transition zone is a very important scientific task. Selection of the southern part of Lemonnier crater was determined, in particular, by the presence here of a geologically interesting, extended fracture of the lunar crust.

During its existence, Lemonnier crater has undergone partial subsidence and destruction, and it was later flooded with lava flows. As a result, its bottom became a bay of the Sea of Serenity, and the portion of the crater wall preserved formed a scarp, on the boundary between the mare plain and the highland Taurus mountain mass.

South of the landing site, the mare surface is bounded by a slightly elevated hilly plain, which has properties, which are intermediate between the characteristics of the typical "mare" and typical "highland" regions. This zone changes to highland terrain towards the south and east. /42

The work program of the Lunakhod was compiled, in conformance with the main set of scientific tasks of joint study of variation in the basic physical-chemical properties of the surface, as a function of the geological-morphological situation in the zone of transition of the mare area of the moon to highland. This task included obtaining geological-morphological and topographical data and study of the magnetic field, chemical composition of the surface layer and the physical-mechanical properties of the soil, as well as the optical properties of the surface.

To obtain the necessary scientific information, a magnetometer, a RIFMA-M X-ray spectral appratus and an instrument for evaluation of the physical-mechanical properties of the soil were installed on the Lunakhod, and special photometric markers, which are plates with 39 fields of different reflecting powers, were inserted into the field of view of the panoramic cameras. The geological-morphological and topographical studies of the terrain were carried out on the basis of photography of the lunar landscape, which included obtaining television panoramas and photographs, as well as telemetry data on the distance travelled and location of the vehicle on the surface of the moon.

In addition, the technical capabilities of the Lunakhod permitted installation of a number of instruments aboard it, intended for solution of other problems of great scientific and technical importance. These were an astrophotometer, measuring the luminance of the lunar sky, a radiometer, measuring the characteristics of cosmic radiation, a Rubin-1 photoreceiver, used for conducting the Lunakhod laser direction finding experiments, as well as a French laser radiation corner reflector. The laser range finding and laser location experiments are for the purpose of precisely determining the coordinates of the Lunakhod and its position, relative to elements of the surrounding relief, as well as the parameters of motion of the moon.

The magnetometer, astrophotometer and Rubin-1 photoreceiver on Luna-1 were not used. Besides changing the composition of the scientific equipment, the capabilities of the RIFMA instrument, analyzing the chemical composition of the lunar soil, were expanded.

In accordance with the tasks of the experiment, changes and improvements over those, which were used in Lunakhod-1, were incorporated into the individual systems of Lunakhod-2. In particular, the frequency of transmission of the television images of the course television cameras was increased. One of them was raised upward on a support, which significantly improved the forward view of the horizontal terrain. The definition of the images received became considerably higher. /43

For convenience in operational use of the television and phototelevision information, certain characteristic details of the relief of the lunar surface in the area of action of Lunakhod-2 were given provisional names by the selenologist specialists. Thus, for example, a small inlet on the southern edge of Lemonnier Crater, located approximately 15 km southeast of the Luna-21 landing point, was given the name of Round Bay. A tectonic fracture, intersecting the mare deposits of Round Bay was called Straight Rille. The names of Near Cape, Far Cape and certain others also were introduced.

The method of study of the lunar surface, with the aid of Lunakhod-2, was worked out, on the basis of experience accumulated during the work of the self-propelled vehicle, Lunakhod-1. The essence of it consisted of a combination of detailed studies of individual sections of the surface and route studies over the entire course of movement of the vehicle. Sections of complex study of the surface can be considered to be reference points along the route of Lunakhod-2. Comparison of the quantitative characteristics obtained at the reference points permits evaluation of changes in the properties of the surface studied along the route of the self-propelled vehicle.

During the first and second lunar days, the self-propelled vehicle, moving southeast and south, left the area of a typical mare nature and entered the hilly highland foothill zone. On the third lunar day, it completed a passage to the east, to Straight Rille. Detailed studies of this interesting formation were subsequently performed.

Within the "mare" section of movement of Lunakhod, it encountered already well-known relief forms on its way -- small craters and, in isolated cases, rock deposits accompanying them. It most often came across strongly smoothed ancient craters. /44

The relative number of so-called secondary craters, formed as a result of impact on the surface of ejecta from larger ones, was successfully estimated. The number of secondary craters from 0.5 to 2 m in size was not over 0.25% of all craters of this size.

The thickness of the upper, strongly reworked layer of the surface (regolith), judging from the depth of fresh craters, varies from 1 to 6 m. These estimates are in good agreement with previously existing ones.

In the hilly highland foothill zone, Lunakhod reached the outer slope of the wall of a 2-km crater. In this case, next to one of the craters, 15-20 m in diameter, landslide terraces up to 10-15 m long were found.

A 2-3 fold decrease in density of small craters from that of the normal "mare" density, was noted in this area. The thickness of the regolith within this hilly plain reaches 10 m in places.

After leaving the highland foothill zone, Lunakhod continued to move to the east, and it reached the area of Round Bay. Formations were noted on 12-17° slopes in this area, in the form of terraces, up to several hundred meters in length.

Continuing to move to the east, Lunakhod came to the tectonic fracture. The rille, 15-16 km long, is located on the southeastern shore of Lemonnier Crater, and it stretches from south to north. Its depth in various parts of the study region varies from 40 to 80 meters.

The time of formation of Straight Rille is in the so-called post-mare period of the history of the moon. This means that Straight Rille formed after the bottom of Lemonnier Crater was flooded with basalt lavas. However, it is not excluded, that the rille is the result of renewal of a more ancient tectonic fracture, /45 signs of which are traced in the direction of the rille, into the highland region, far beyond Lemonnier Crater.

Tectonic fractures of the Straight Rille type are objects on the lunar surface, which are geologically very interesting, and which indicate movements of large sections of the lunar crust taking place in the past. Ancient tectonic seams, which have been well-studied on earth, are similar. However, because of the intensive processes of erosion under earth conditions, they are strongly smoothed, as a rule. Tectonic fractures are preserved on the moon, for periods of billions of years, and they make it possible to observe the vertical cross section of its surface layer.

On the eastern and western boundaries of the rille, zones 30-40 m wide were found, of unilateral intensive displacement of lunar material in the direction of the fracture. With approach to the rille, the thickness of the regolith systematically decreases and, at the lip of the fracture, over the entire extent of the part of the rille studied, the bedrock is exposed, in the form of a continuous rocky "border." Fragments of the exposed rocks frequently are up to 1-2 m in size and more.

Below the rocky "border," the steepness of the rille wall increases, reaching 30-35°. The slopes are covered with talus here, consisting of large blocks and stones.

Thus, by means of Lunakhod, an outcrop of bedrock, up to several tens of meters thick, has been located in this part of Lemonnier Crater.

Selective, detailed studies of individual formations was carried out along the course. They showed that the mechanical properties of the soil changed within broad limits. The bearing capacity varied from 0.1 to 1-1.5 kg/cm^2. However, the overall nature of distribution of the mechanical characteristics of the soil over the surface are quite close to data obtained from Lunakhod-1. During measurement of the mechanical properties of the soil, sections with increased sag, as well as with small layers of loose material on a solid base, were found.

In preparing modified RIFMA-M instrument, special attention was given to obtaining series of data on the content of the most /46 characteristic chemical elements, especially iron, in the rocks of the moon. This was because of the fact that the iron content in the highlands was less than in the mare. Determination of the ratio of iron content to that of other elements, for example, aluminum and titanium, also is of great importance in study of the transition zone.

The first measurements with the RIFMA-M apparatus were carried out at a short distance from the landing stage of the spacecraft, on the wall of a 40-m diameter crater. The silicon content here proved to be 24 ± 4%, calcium 8 ± 1%, iron 6 ± 0.6% and aluminum 9 ± 1%. (Measurements made by Lunakhod-1 in the Sea of Rains showed an iron content of 10-12%).

During movement of Lunakhod to the south, a 13-m diameter crater, approximately 1.5 km distant from the landing site, was investigated. The soil in this area turned out to be similar in composition to the section studied first.

As Lunakhod-2 moved towards the hills, located to the south, the iron content began to decrease and, at a distance of 5 km from the landing site, it was 4.9 ± 0.4%. In a session carried out on 19 February, the lowest iron content was recorded, 4.0 ± 0.4%. The aluminum content simultaneously increased to 11.5 ± 1.0%. In this manner, by menas of the RIFMA-M instrument, changes in the chemical composition of the surface were recorded, which were connected with different rocks in the "mare" and "highland" areas.

During movement along the planned route, Lunakhod crossed a region which reflects sunlight differently. Since the color and reflecting properties of the lunar material say much of its chemical composition, the type of rock in one area or another on the moon can be decided indirectly from it. Comparison of the reflecting properties, known from ground observations, as well as from the results of space photography of the moon, with the structural characteristics of its surface, permits determination of the nature of the cover of other little-studied areas of it. This circumstance considerably enlarges the importance of the scientific results obtained by the second Lunakhod. Study of the reflecting properties /47 of the surface was provided by the presence of the photometric markers in the field of view of the telephotometers.

The results of preliminary processing show that remote determination of the type of the lunar surface material from its reflecting powers coincides with the chemical composition data, obtained by means of the RIFMA-M instrument.

In the modern epoch, the moon does not have a noticeable overall megnetic field. At the same time, local magnetic fields have been found on the surface of the moon. Their nature and origin still remain unknown. In all likelihood, they are connected with residual magnetism of the rocks of the moon, preserved until the present.

During the entire time of operation of the Lunakhod, magnetic measurements were carried out continuously during movement and at stops. A preliminary analysis of the data permits it to be noted that the magnetic field on the surface of the moon is very irregular.

In the magnetograms, obtained during stops of the Lunakhod, certain characteristic changes in the field were revealed, indicating processes of current induction in the moon, due to the changing interplanetary fields. This permits determination of the conductivity of the moon at depths on the order of hundreds of kilometers and, in this manner, some ideas of its internal structure to be obtained.

In accordance with the Soviet-French agreement on cooperation in the field of space research, an angle reflector was installed on Lunakhod-2, intended for conduct of laser location experiments. This makes it possible to directly determine the distance to fixed points on the lunar surface, at which the light reflectors were installed. The high accuracy of these measurements permits the basic parameters of the "earth-moon" system to be refined by several orders of magnitude and a number of scientific and practical problems to be solved this way.

Regular laser location measurements of the distance to the Lunakhod-2 reflector were begun by the Physical Institute, Academy of Sciences, USSR, with the 2.6-m telescope of the Crimean Astrophysical Observatory, in June of this year, and they are continuing up to the present time. 2-4 measurement sessions are carried out monthly. The measurement process consists of sending powerful laser pulses, on the order of 10^{-8} sec long, to the reflector, formed into a narrow beam by means of the telescope, and of subsequent reception of the reflected signal, attenuated 10^{19}-10^{20} times on the path to the moon and back. /48

The distance to the reflector is determined by the propagation time of the laser pulse. The accuracy of measurement of the time interval is 10^{-8} sec.

Each measurement is a series of several hundred light pulses at 3 sec intervals. The statistical accuracy of determination of the distance between the source of the pulses and the reflector installed on the moon is ±40 cm.

In accordance with the plan of scientific experiments on use of optical quantum generators (lasers) in study of space, a Rubin-1 laser radiation photoreceiver was installed on Lunakhod-2. It was intended for working out a system of measurement of coordinates of lunar space stations. During the period of operation of Lunakhod, a number of sessions were carried out, with the Rubin-1 photoreceiver switched on.

Laser direction finding was accomplished, by means of optical quantum generators, installed in the high mountain observatory of the P. K. Shternberg State Astronomical Institute, in the mountains of the Zailiyskiy Alatau, near the city of Alma-Ata, and at other points in the Soviet Union. The divergence of the laser beam, passing through the optical system of the telescope, is decreased to several angular seconds. By means of a special mechanism, this beam accomplished a spiral survey of the Lemonnier Crater area. The direction of the radiation of each laser pulse was recorded on photographic film, simultaneously with photographic recording of the moon. To fix the direction of the beam in the telescope tube, a corner reflector was installed, which returned a small part of the radiation through the telescope, strictly parallel to the axis of the radiated pulse. When the laser beam hit the Rubin-1 photoreceiver, transformation of the light energy into electricity takes place in it, and a "radio acknowledgment" of entry of the beam is transmitted to earth.

The observatory entered a stable optical connection with Lunakhod-2, and it conducted sessions of precise measurements of its selenographic coordinates. A total of over 4000 hits of the laser beam on the Rubin-1 photoreceiver were recorded, and 1500 photographs of the moon were obtained, with laser beam direction markers, for determination of the location of the Lunakhod. The data obtained permitted determination of the coordinates of the Lunakhod with high accuracy, independently of other measurement methods. /49

During the period of operation of the self-propelled vehicle, the astrophotometer installed aboard it was switched on 14 times, which permitted measurement of the brightness of the lunar sky. The brightness in the visible range of the daytime and "twilight" (after the sun set beyond the local horizon) of the sky of the moon proved to be unexpectedly high. At the same time, the simultaneously measured luminance of the lunar sky in the ultraviolet turned out to be low.

These data need further experimental refinement, but they may, in particular, indicate that the moon is surrounded by a layer of dust particles, which strongly scatter visible sunlight and earthlight.

Measurements also were carried out in the deep lunar night, when the astrophotometer, aimed at the local zenith, cannot "see" such dust, illuminated by the sun. It turned out that the brightness of the lunar sky in this case is only a little more or the same as that measured from satellites in circumterrestrial space on the dark side of the earth.

Thus, the sky above the moon is sufficiently "dark," to carry out ultraviolet astronomical observations from its surface, both in the daytime and the nighttime. Concerning observations in visible light, conditions on the moon most likely are different during the lunar day and the lunar night.

During the lunar days, continuous measurements of the intensity of corpuscular radiation of solar and galactic origin were made from aboard the self-propelled vehicle. In this case, the radiation situation was quiet in the area of the moon.

The scientific observation and measurement data presented above is supplemented by materials from further processing and analysis of the results. /50

Execution of the program of experiments by means of Lunakhod-2 was accomplished by an operational control group, including an engineering-design staff, scientists and the Lunakhod crew. It is important to note that, while putting the Soviet program of study of the moon and planets into practice by means of automatic spacecraft, a large group of specialists was first trained in our country, for solution of the problems of remote control of an object, located on the surface of another heavenly body. Rich practical experience was accumulated during the operation of Lunakhod-1. Subsequently, the Lunakhod crew, by means of systematic training exercises, continually improved their skill and, as the results of operation of Lunakhod-2 demonstrate, they know how to manage all difficulties arising during movement of a self-propelled vehicle, under severe conditions of heavily broken terrain, loose soils, steep slopes and extensive rock deposits, with honor. The accumulated experience, together with design improvements in maneuverability and mobility of a self-propelled vehicle, permitted Luankhod-2 to cover a record distance under these difficult conditions, and to carry out studies along a course 37 km long.

During the entire period of operation, the onboard systems and structure of Lunakhod withstood significant dynamic loads and tolerated the sharp temperature fluctuations well.

The planned research program was completely performed. The scientific data obtained during the long experiment are an important contribution to the science of the moon, and they facilitate systematic accumulation of new knowledge of the origin and evolution of the solar system.

N75 22260

The Colors of Space

K. Kondrat'yev, A Nikolayev and V. Sevast'yanov

An important part of the scientific programs carried out in /51 manned spacecraft and long-term orbital stations is systematic visual observations of the surface of the earth and optical phenomena in the atmosphere. The first astronaut, Yu. A. Gagarin, estimated the possibilities developed here. Visual observations of optical phenomena supplement photographic and instrumental measurement data, and they were an important means of study of the natural environment and natural resources, in the interests of science and the national economy. Such complex studies began with the flights of the Soyuz spacecraft and the Salyut orbital station.

In Soyuz-3, G. T. Beregovoy observed the phenomena of the transition region from the zone of the twilight aureole to the zone of night illumination of the atmosphere, during sunset. Thus, information was obtained on the radiant irregularities in the upper atmosphere. On the basis of measurements, which Ye. V. Khrunov made by means of a spectrograph aboard Soyuz-5, the altitude of the bright upper boundary of the luminous night layer (90-95 km), was determined, which was of great importance in interpretation of the nature of this phenomenon.

The Soyuz-9 crew first carried out systematic and detailed observations of optical phenomena in the atmosphere of the earth. They were noted continually, during the entire flight, in strictly defined regions of the terrestrial atmosphere. This served as a basis for constructing a global picture of development of optical phenomena on the night side of the earth, in the twilight region and on the day side of the planet. Data from Soyuz-3, Soyuz-4, Soyuz-5 and Soyuz-9 permitted compilation of a picture of sequen- /52 tial development of optical phenomena close to the night, twilight and daytime horizons of the earth.

One of the most impressive spectacles is the appearance of the terrestrial atmosphere next to the twilight horizon. When the spacecraft is in the shadow region and approaches the terminator, a sickle-shaped region is seen in the direction of the twilight horizon, which is colored with different colors at different levels. According to visual observations from Soyuz-4 and Soyuz-5, the edge of the earth is distinguished as a distinct black line. Next to the surface of the earth, the twilight aureole is colored a strongly saturated orange-red tone. With increase in altitude, the color of the aureole changes smoothly to yellow-orange and yellow. Further, there is a narrow dark blue band of reduced brightness, and a region colored a light azure tone is located immediately beyond it. Weakly saturated azure colors and a light azure tone, with a whitish tinge appear. This region occupies approximately two-thirds of the height of the aureole and, on the boundary of outer space, it is colored a dark violet tone. The colors of space dawns are perceived as soft and delicate, and one color changes smoothly into another.

Observations of the color range of the twilight aureole are of great technical importance. Theoretical calculations show that the sequence of color hues of the aureole can be an indicator of the composition of the upper layers of the atmosphere. The nature of the coloring of the twilight aureole depends, for example, on the ozone content.

It is interesting that astronauts give different descriptions of the color picture of the twilight aureole. Thus, according to the impressions of V. V. Nikolayeva-Tereshkova, the lower part of the aureole, colored red-orange and yellow tones, passes through a broad off-white band, to light azure, dark blue and blackish violet. K. P. Feoktistov registered a somewhat different picture. The vertical evolution of the color tones of the twilight aureole appeared this way to him: from red-orange to yellow, azure and off-white, then immediately to azure and off-white and again to azure and off-white.

Detailed observations of the vertical evolution of the color of the twilight aureole were made from Soyuz-9. According to them, /53 dawn began to appear in the form of a tiny dark-red sickle. Then, before formation of the primary color range of the twilight aureole, a lightening progresses above the sickle, in that part of the atmosphere, which is adjacent to the lower part of the aureole. After this, orange-red and yellow are added to the dark-red tones. With decrease in the angle of the sun below the horizon, the dimensions of the region of the sky occupied by the colored twilight aureole increases. The twilight aureole is characterized by this vertical structure of color tones: red, orange, yellow, pale azure, off-white, pale azure again, then off-white, azure, blue, violet and black. The maximum angular height of the aureole is directly before sunrise. At the moment of the appearance of the first rays of the sun, the aureole is compressed, suddenly decreasing by approximately one-third in vertical dimensions.

When the sun has risen, but the spacecraft still is above the shadow region, the central part of the zone previously occupied by the aureole loses its color features. The sun shines on the dark background of space, and the characteristic illumination of the aureole in the form of "whiskers " is observed in the direction of the terminator, to the right and to the left of the star. An analogous phenomenon occurs during sunset, but the vertical dimension of the yellow-red region of the "whiskers" decreases. At the moment of passage of the terminator, the colored "whiskers" generally disappear.

The color features of the twilight aureole which we have reported approach the data of K. P. Feoktistov most closely of all.

Some dissimilarity in the description of the color distribution and height geometry of the twilight aureole of different astronauts indicates a unique meteorological situation in the terrestrial atmosphere during the flights. Singularities in the vertical irregularities of the atmosphere show up here.

It also must be considered that the perception of color of each person is subjective and depends on the optical characteristics of his eyes and certain physiological features of vision. In connection with this, the importance of objective colorimetric data is increasing. They can be obtained, when the spectral brightness of /54 the twilight aureole is known.

The results of observation of the atmosphere next to the daytime horizon of the surfaces of the continents and oceans, carried out by the astronauts from the Soyuz spacecraft, differ little in general. When a spacecraft goes out of the shadow into the illuminated side of the earth, the line of the daytime horizon is washed out by a veil of haze. There are no noticeable vertical irregularities in the brightness of the haze. Its color depends on the height of the sun and the cloud cover. Thus, the cloudy atmosphere above the ocean has a dirty gray color next to the horizon, but a bright azure, if there are no clouds. The vertical evolution of the haze color is simple, from an azure hue (or dirty gray) to blue, changing higher to the black color of space.

The line of the horizon is seen faintly on the day side of the earth, but its curvature is noticeable. A narrow azure band is observed above the daytime horizon of the earth, which is washed out at the boundary with the black color of space. The surface of the earth usually is covered with clouds at the daytime horizon. The color of the sky above the region occupied by the atmospheric haze is black. On the daytime side of the earth, the visibility of its surface and landscape remains clear at relatively small sighting angles. However, at large angles, because of the foreshortening of the image and the effect of the atmospheric haze, the picture is distorted.

From the altitude of spacecraft orbits, i.e., from approximately 200-250 km, large and small lakes, rivers, forest masses and their boundaries, cities and settlements are seen well. Mountain ranges, snow on the mountains, aircraft contrails and cloud shadows on the surface of the earth are distinguished clearly. It is easy to identify all cloud formations, cyclones, stratus and cumulus clouds and cloud banks. Horizontal and vertical movements of cloud layers are noticeable. The colors of the earth's surface are distinguished well from the spacecraft window. Thus, sand ridges, elongated in the latitudinal direction are clearly distinguished by color in the sahara. The swells can be noticed on the ocean surfaces, and bands of surf stand out distinctly.

The transparency of the atmosphere is different above the geographical areas of the earth. The Soyuz-4 and Soyuz-5 crew members gained the impression that the cleanest atmosphere above the Pacific Ocean was in the area of the Kurile Islands and Kamchatka. The air above the continents is more turbid than above the oceans. The atmosphere is very clean in the mountains. This is confirmed by photographs made from the spacecraft. /55

It is generally of interest to compare the capabilities of photography and visual observation of the earth from space. In comparing the picture of the surface of the earth, as it is observed from aboard a spacecraft, with its image on a photograph, the impression is created that the photo was made through some scattering shroud. The contrast of the photographs always is less than in observation with the unaided eye.

Thus, the visual observations of the astronauts are a valuable source of information on the physical processes taking place in the atmosphere of the earth. Precisely owing to them, a number of new phenomena were successfully found, in particular, the vertical ray structure of the daytime radiation of the upper atmosphere, illumination in the area of the south pole and equator, the "whiskers" effect and others. All this could scarcely have been recorded from space, even by means of very complicated apparatus.

Of course, the main prospects for study of the natural environment from space involves use of automatic apparatus and complicated instruments, requiring the participation of man. This primarily concerns study of specific objects or phenomena. However, it is just as indisputable that an important role in first stage studies, preceding systematic study of the natural environment with various devices and instruments, will always remain with visual observation in the future. In connection with this, the importance of scientifically substantiated in-flight observation programs is increasing considerably.

Purposeful study of natural phenomena from space is only beginning. However, the successes already achieved lead to the conclusion that the presence of qualified astronaut specialists aboard long-term orbital stations is playing an important part in study of various natural phenomena.

N75 22261

Prognoz Reports

G. Narimanov and N. Pisarenko

The orbit of the Prognoz satellites was selected, so as to conduct studies from areas located outside the effect of the magnetic field of the earth during the greater part of the period of revolution. Under such conditions, the interference from particles captured by the geomagnetic field decreases noticeably and, moreover, observation of the unperturbed "solar wind," the flux of charged particles continually given off by our star, is possible. Why is it necessary to study solar activity, especially outbursts and the phenomena connected with them? /56

The question concerns one of the most surprising and impressive phenomena of nature. Gigantic explosions on the sun take place most often in the period of its maximum activity, which is repeated every 11 years, on the average. One of the models of their formation assumes the following development of the event. Thermonuclear reactions take place inside the sun, under conditions of very high pressures and temperatures. However, the resulting energy cannot be "forced" outward through the dense, opaque plasma layers. Only through some intermediate processes of absorption and emission of the thermonuclear reaction products, does convective (mechanical) transport of a mass of strongly heated matter from the inner areas to the outer layers, to the photosphere, take place. Here, it uses up energy in radiation, cools off and sinks inside, yielding its place to hotter portions of plasma. The surface of the sun boils, as it were, liberating the accumulated energy.

However, at times, persistent regions of somewhat lower temperature appear on the relatively uniform surface of our star. They appear dark on a bright background and, therefore, they are called sunspots. Strong magnetic fields, exceeding the normal /57
background level on an "unperturbed" portion of the surface of the

surface of the sun by a thousand times or more, are always observed around them.

The magnetic effect of the spots decreases the convection of the solar plasma in its zone and, as it were, "accumulates" part of the energy included in the convective motion. The magnetic fields of a group of spots can have a complex configuration and, sometimes, they mutually destroy themselves, creating the so-called "neutral" bands, along which strong electric currents are generated. They are unstable, and they sometimes discontinue for a short time, forming strong electric fields in the break, which accelerate the plasma particles to high energies. This accelerated flux, reacting with the plasma, produces an explosion. Electromagnetic oscillations are simultaneously excited over a broad frequency range (X-ray radiation, radio surges, ultraviolet radiation).

There other models. However, the general picture of formation and growth of the bursts still is not sufficiently clear. Further study and all its consequences are required. What do we now know about this?

Fluxes of charged particles, accelerated at the moment of the explosion, partially overcome the barrier of the magnetic fields around the sun and enter the interplanetary medium. Moreover, bursts, especially large ones, almost always are a source of a shock wave, which propagates in all directions for tens of thousands of kilometers. By its interactions with the magnetic fields of the sunspots, intense acceleration of the charged particles, especially of protons, possibly also takes place. Fluxes of them are a serious radiation hazard in flights of man in space.

The "breath" of the bursts is felt in the immediate vicinity of the earth, the magnetosphere. Experiments have shown that there is an interrelation of various processes within the magnetosphere with solar activity. Thus, the "solar wind" deforms the geomagnetic field of the earth and gives it a shape somewhat like a drop. On one side of our planet, the boundary of the magnetosphere, "drawn in" by the solar wind, is located at a distance of 10 earth radii from the earth, and the space between the shock front and the magnetosphere boundary is the so-called transition region, where hot plasma is encountered. On the opposite, "shadow" side of the magnetosphere, a loop of the geomagnetic field forms, extending to a hundred or more earth radii. As a result of the perturbation by the solar wind, the geomagnetic field experiences responding perturbations, manifested in the form of magnetic storms and auroras. /58

One of the most remarkable formations inside the magnetosphere is the zone of captive radiation or the radiation belts of the earth, consisting almost entirely of electrons and protons. The dynamics of the radiation belts are closely connected with perturbations in the interplanetary medium, magnetic storms and auroras.

X-ray and short wave radiation of the sun has a great effect on the nature of geophysical phenomena. They cause breakdown of molecules by light, formation of new molecules and atoms and they determine the composition of the upper atmosphere of the earth. The electromagnetic radiation of the sun is the basic source of heating of the upper atmosphere of the earth. It participates in formation of the ionosphere, and it determines the composition, density, temperature and ionization of the upper layers of the atmosphere.

However, this still is not all. The effect of processes taking place on the sun is felt by the entire biosphere of the earth, its animal and plant worlds. Thus, the weather, the growth rate of trees, "surges" in the insect populations, locusts for example, and the spread of certain diseases depend on the growth of solar activity during the 11 year cycle.

The number of similar examples is increasing rapidly, and it is forcing deeper study of the nature and patterns of development of all forms of solar activity, as well as of the mechanisms of transmission of perturbations from the sun, through the interplanetary medium, to the earth. It is very important to learn to predict the appearance of bursts and the various effects caused by them. One can agree with the opinion of many prominant scientists, that creation of a sun service is no less important for the national economy than the work of the meteorological and seismological services.

In the orbital solar observatories of Prognoz, many experi- /59
ments are being carried out, which should give the information necessary for study and modelling of the physical picture of solar activity phenomena and methods of predicting them.

By means of X-ray and gamma ray spectrometers, time monitoring and spectral analysis of the electromagnetic radiation of the bursts over a broad energy range are being carried out. A group of instruments, charged particle detectors and spectrometers, are intended for study of the behavior and angular distribution of protons and electrons produced during bursts. These instruments are studying the propagation patterns of charged particle fluxes in the interplanetary medium. Others are investigating the characteristics of perturbations in the solar wind and the interplanetary magnetic field. Experiments also are being carried out, to study the long wave radio radiation and low frequency electromagnetic oscillations in the interplanetary medium and the magnetosphere of earth.

The first data obtained from the Prognoz, Prognoz-2 and Prognoz-3 satellites have returned interesting results. First and foremost, scientists obtained the capability of regularly following the radiation situation in the interplanetary medium around the earth. Beginning 14 April 1972 (the moment of launch of the first satellite of the Prognoz series), there has been continuous information on the charged particle fluxes, solar wind and X-ray radiation of the sun. This has permitted a statistically significant picture of the radiation conditions in circumterrestrial space to be obtained. For example, from April to November 1972, interplanetary space was filled with intense fluxes of solar protons with energies of several million electron volts and electrons with energies of tens of kiloelectron volts. Such an abundance of particles in a period of minimum solar activity is unusual.

Against this increased background, which is created by relatively low energy charged particles, large solar bursts have been observed several times. The sun was especially active at the beginning of August 1972. The largest bursts in the last 20 years took place on 2, 4 and 7 August, accompanied by intense fluxes of protons and electrons. The instruments installed on the Prognoz /60
and Prognoz-2 satellites recorded this unique natural phenomenon in circumterrestrial space. Dosimetry measurments showed that the absorbed dose inside a spacecraft, were it in orbit at this time, would have been of an amount dangerous to human health.

Scientists also have detected several very interesting phenomena accompanying this series of bursts. An example is a narrow increase in the flux of particles of almost all energy ranges, with very steep leading and trailing fronts. This unique "tube," several million km in diameter, extended from the sun to the boundaries of our system, and it was formed by the lines of force of the interplanetary magnetic field, apparently connected to the burst area at one end. The mechanism holding the particles in this tube is still insufficiently clear. The profiles of the X-ray radiation surges of the bursts have a periodic structure. It is evidence in favor of a model, which considers the optical burst to be the result of the interaction of accelerated particles with the matter of the solar atmosphere, i.e., to be a secondary phenomenon.

In the time of the increased solar activity in August of 1972, as a result of the effect of the accelerated solar particles and the solar wind, the magnetosphere of the earth was strongly deformed. Initially, in the compression phase of the magnetic storm, its radius was reduced to almost half that in the unperturbed state and, in the recovery phase, the magnetosphere expanded almost 2-fold in the direction of the sun.

Data obtained from the Prognoz unmanned satellites are compared with the results of ground astronomical observatories and geophysical stations, an extensive network of which envelopes almost the entire planet. Scientists are persistently seeking the capability of predicting solar activity phenomena.

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Radio Bridges Through the Universe

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The problem of increasing radio reception sensitivity, which /61
has always been of great importance in radio engineering, has become especially acute in the space research epoch. This is completely understandable: in order to study very remote objects and receive information from them, extremely weak radio signals must be recorded.

Until recently, electronic instruments of the vacuum radio tube type or semiconductor crystals were used in receiving devices. Their sensitivity is limited by internal noises, connected with the thermal motion of electrons participating in the process of receiving radio signals. A radical solution of the problem of creating "low-noise" receiving systems was found, by way of using the fundamentally new quantum method of radio wave amplification.

In quantum amplifiers, the phenomenon of forced radiation of atoms, during their transitions from one energy state to another by the radio signals received, is used. These radiations, as it were, supplement the energy of the weak signal, as a result of which it is amplified. Crystals which contain paramagnetic ions are used as the active agent in the quantum amplifiers, replacing radio tubes or semiconductors. The crystals are placed in an external magnetic field, usually created by electromagnets with superconducting windings.

The paramagnetic crystal is cooled to the liquid helium temperature (-269°C), as a rule. Owing to this, as well as because of the absence of current carriers in the crystal, the inherent /62
noises of quantum amplifiers are a hundred times less than in regular radio receivers. The use of such amplifiers permitted radio engineering, for the first time in history, to increase the

sensitivity of radio receivers to the fundamental limit, determined by the "noise" radiation of the universe.

Much work has been carried on in the Soviet Union in the last decade, to build and use quantum amplifiers. Fundamental research has been carried out, in the course of which rubies, which exceed other materials in their characteristics, were first used in the amplifiers. Different quantum amplifiers have been developed, receiving radio waves in the decimeter, centimeter and millimeter ranges. These devices have been incorporated into ground receiving systems for study of space (radar ranging of the planets, radio astronomy, deep space communications). Quantum amplifiers are unique devices. At the present time, they are being exploited in the largest antennas in the USSR and USA. To the point, we note that, in the shortest radio waves, in the millimeter range, foreign developments of such receiving devices have not been crowned with success. They have been used successfully in radio astronomy for a number of years in the USSR.

Quantum amplifiers have significantly expanded the capabilities of planetary radar ranging, by sharply reducing the time necessary for accumulation of information. To a great extent, this has determined the success of planetary radar ranging studies, carried out under the leadership of academician V. A. Kotel'nikov. Thus, information on the planet Mercury, obtained by use of a quantum amplifier, in 10-15 days of the period of its closest approach to earth, would have to be accumulated over a period of several dozen cycles of approach of the planet, repeated every three months, by regular methods. In other words, this work would have to be stretched out over a little less than 10 years.

One of the major fields of modern radio astronomy is study of the natural cosmic radio radiation, which is concentrated into comparatively narrow frequency intervals, spectral lines. Among such experiments were, for example, obtaining information on the

radiation of neutral interstellar hydrogen at the 21 cm wave- /63
length. They have permitted accumulation of fundamental data on the structure of the universe. However, this line does not make it possible to study the region of ionized and excited hydrogen, representing a major component part of the galaxy. Spectral radio radiation lines, permitting valuable information on these fields to be obtained, are of very low intensity. Only because of quantum amplifiers have Soviet scientists detected and studied these spectral lines for the first time in the world, obtaining valuable information on the structure and dynamics of a number of regions of the galaxy. The recent recording of the first excited hydrogen line in the millimeter range, by means of the USSR Academy of Science Physics Institute radio telescope, has permitted a transition from simple study of the characteristics of the source as a whole, to study of the physical conditions inside it.

Among the most promising areas of radio astronomy is the so-called coherent super-long base radio interferometry (SLBI). This method is based on observations of a radio source independently, by two telescopes a long distance apart. The signals are received at the same time at both points, they are recorded, and they are then processed jointly by computer. The SLBI method is distinguished by high resolution. The longer the base and the shorter the wavelength, the higher it is. It gives the capability of studying the structure of exceptionally interesting objects in space, which are extremely compact on the cosmic scale, quasars, the nuclei of galaxies, star formation regions, etc.

Joint Soviet-American studies of such objects have recently been carried out on a radio interferometer with a super-long base: one radio telescope is located in the USSR and the other, in the USA. The signals were received at a wavelength of 3.55 cm. With this base, the resolution was on the order of one ten thousandth of an angular second, i.e., considerably better than in optical star interferometers. The maximum sensitivity was ensured by use of quantum amplifiers at both ends of the base. As a result, the study of very remote, compact objects was successfully begun. /64

A further increase in resolution of SLBI involves a change to still shorter wavelengths, 1.35 cm. It is of particular interest to radio astronomy, since signals on this wavelength carry information on the presence of water vapor in space. However, in order to carry out such observations most effectively, a considerable increase in sensitivity of the apparatus in this range is required. The corresponding quantum amplifier was developed very recently in our country. It has exceptionally low inherent noise.

Super-long base radio interferometry is providing science with broad prospects. For example, it permits experimental testing of the general theory of relativity on the curvature of a beam of electromagnetic waves by the gravitational field of the sun. The accuracy of such measurements is 100 times higher than by optical methods. Recording of movements of terrestrial continents with an accuracy of a few centimeters also is permissible, by means of SLBI.

Quantum amplifiers have sharply increased the effectiveness and information content of communications from interplanetary unmanned spacecraft. They have been used in various space experiments, in particular, for receiving scientific information from the Mars unmanned spacecraft. In further studies of Venus and Mars, the volume of scientific information will undoubtedly increase. Therefore, the importance of quantum amplifiers, used in radio receiving systems of remote space communications, will be still greater.

In the future, during the flights of unmanned spacecraft to the mysterious planet Jupiter and to the more distant planets of the solar system, the problem of ensuring the necessary information content is complicated considerably, because of the gigantic distances separating them from earth. Under these conditions, it is difficult to overestimate the role of quantum amplifiers, which have the limiting high sensitivity.